Geosyntec consultants

Vapor Intrusion Modeling and Risk Management

Robert Ettinger

2011 SAM Fall Forum

September 22, 2011

Geosyntec consultants

Use of Models for Vapor Intrusion Pathway Evaluation

Models can be used to evaluate the vapor intrusion pathway, but there are questions about their use

- Do models tend to underestimate or overestimate risk?
- Under what scenarios are models applicable?
- How can models be used in the decision-making process?

Modeling vs Monitoring

- Models can aid in the determination of corrective action strategies and/or remediation objectives
- Risk evaluation for *potential* exposure scenarios can be addressed with modeling
- Indoor air sampling may be impractical

Some combination of data collection and modeling may be helpful for VI pathway evaluation

Vapor Intrusion Models

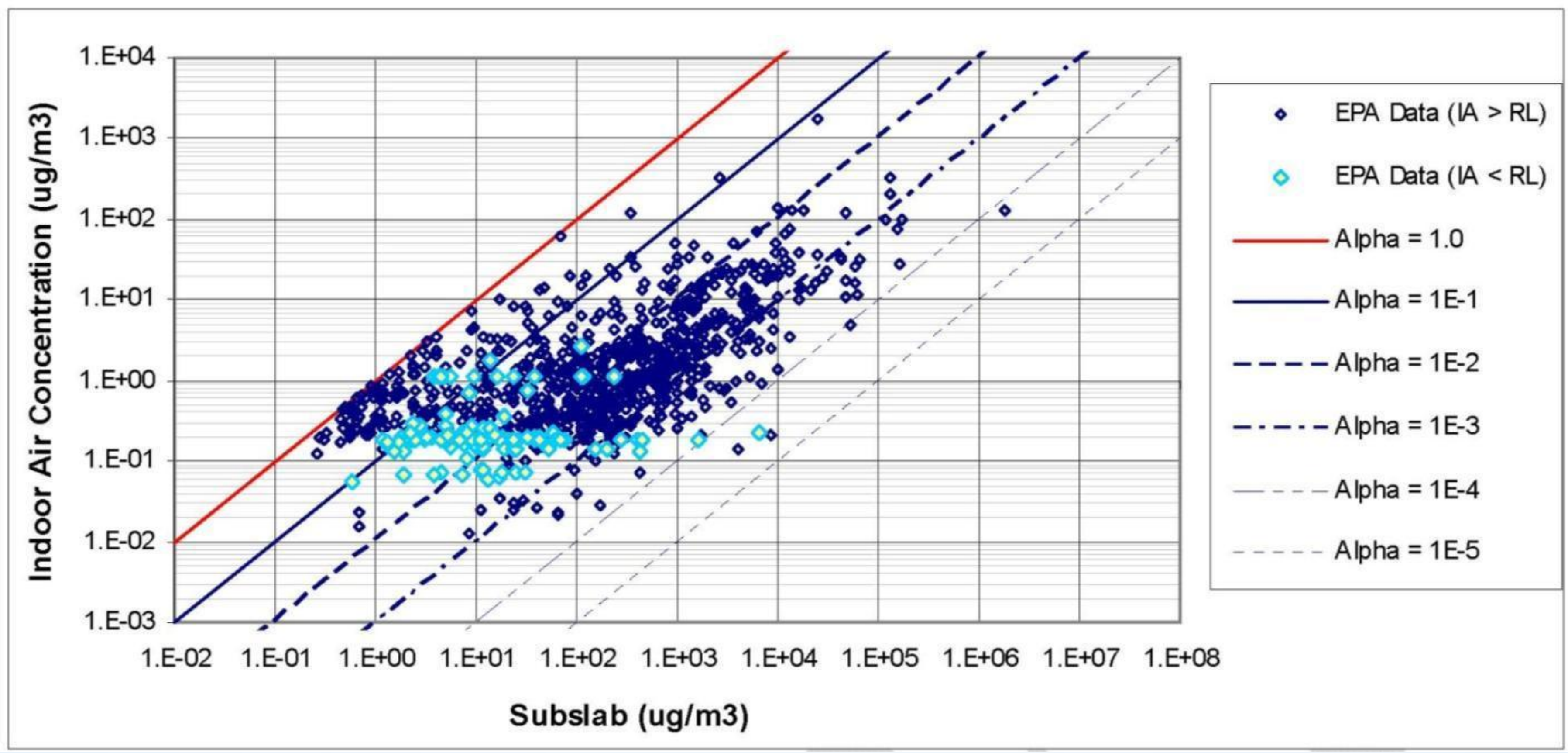
Empirical	Analytical	Numerical
USEPA Database	Johnson and Ettinger (1991)	VAPOURT (1989)
Utah DEQ Database	Little et al. (1991)	Sleep & Sykes (1989)
	San Diego SAM	RUNSAT (1997)
	VOLASOIL (1996)	Abreu & Johnson (2005)
	Krylov and Ferguson (1998)	VIM (2007)
	DLM - Johnson et al. (1999)	Brown University (2007)
	DeVaull (2007), BioVapor (2010)	

- Wide range of vapor intrusion models available
- Model selection dependent on site characterization and detail of assessment needed

Geosyntec consultants

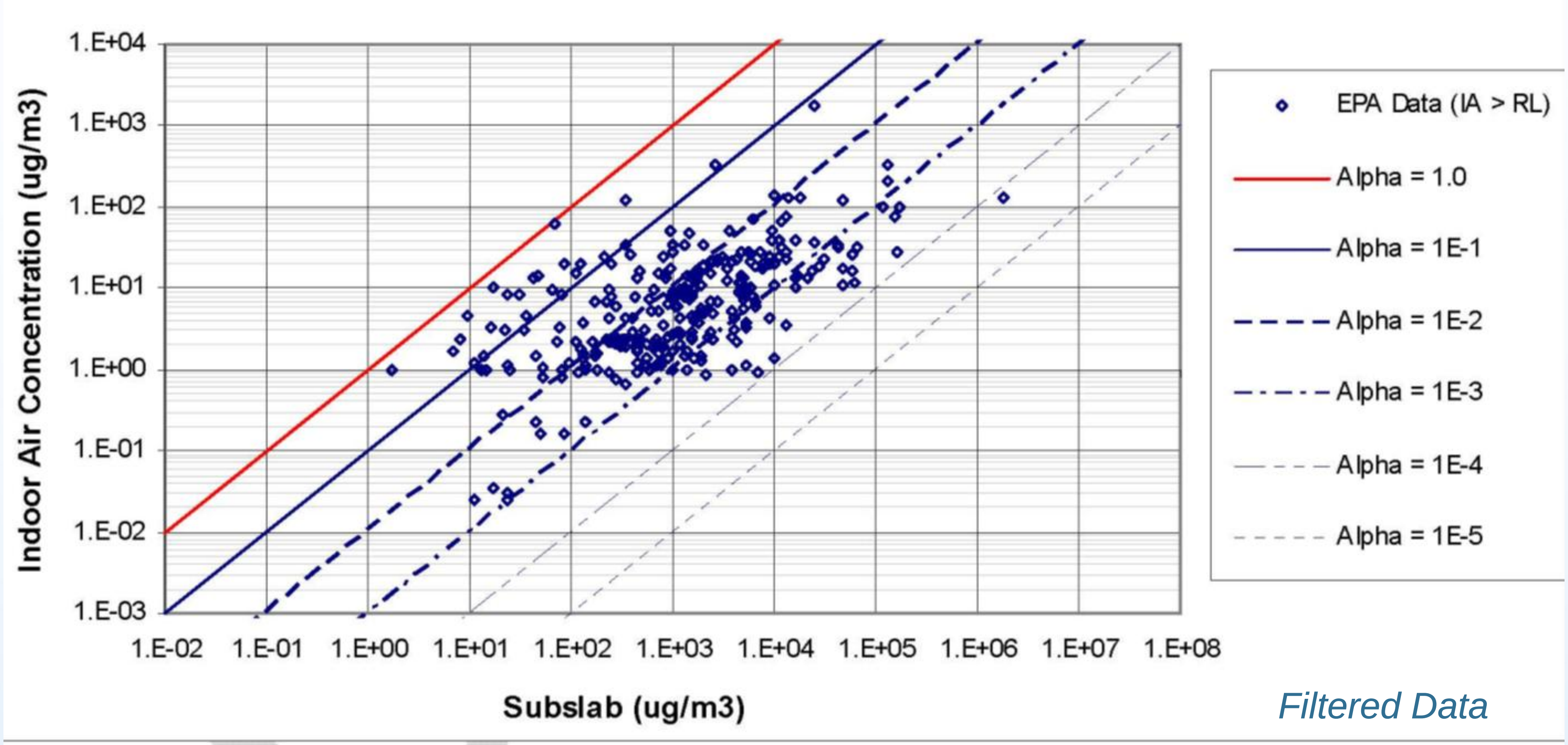
USEPA Empirical Attenuation Factors

EPA database of vapor intrusion investigation data used to estimate empirical attenuation factors

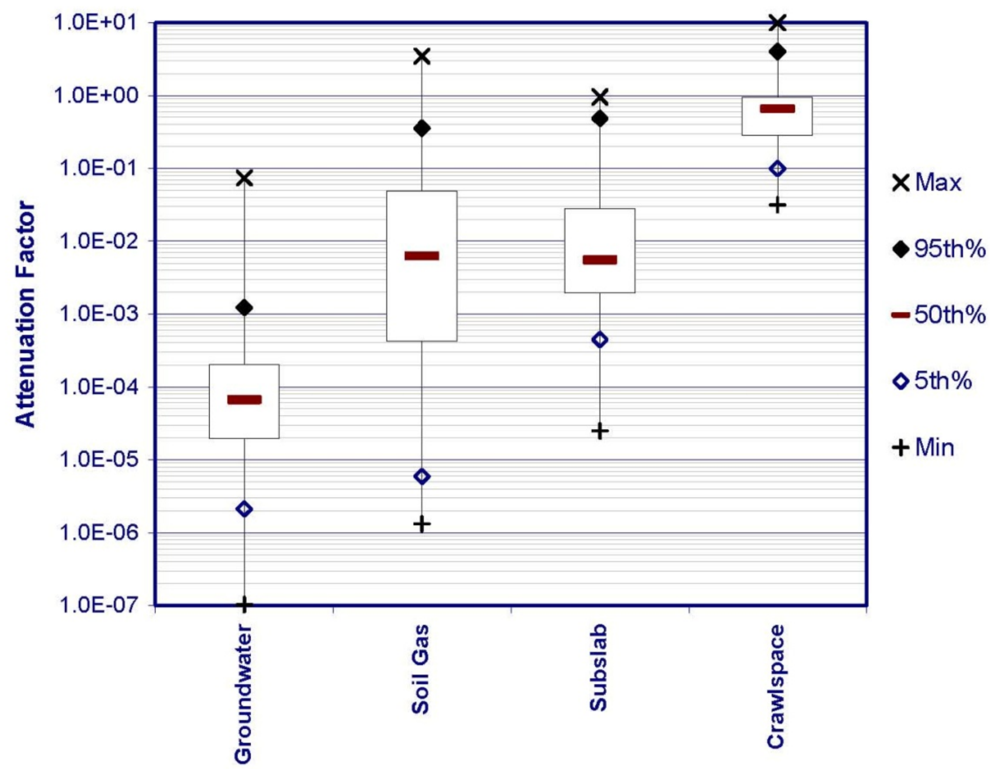


USEPA Empirical Attenuation Factors

EPA recognizes importance of accounting for background sources, but difficult to completely address background and



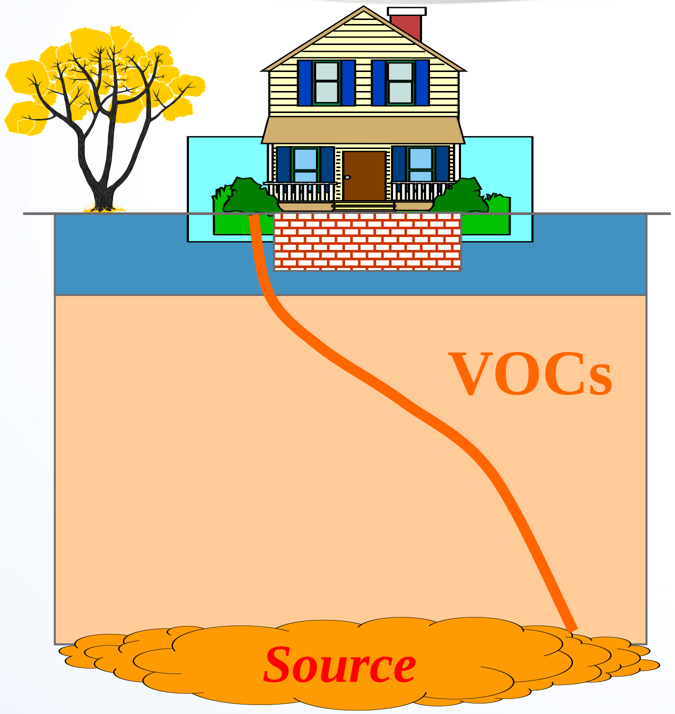
USEPA Empirical Attenuation Factors



Statistic	Groundwater	Soil Gas	Subslab	Crawlspace
0%	1.0E-07	1.3E-06	2.5E-05	3.2E-02
5%	2.1E-06	5.9E-06	4.5E-04	1.0E-01
25%	1.9E-05	4.2E-04	1.9E-03	2.8E-01
50%	6.7E-05	6.3E-03	5.5E-03	6.5E-01
75%	2.0E-04	4.9E-02	2.8E-02	9.6E-01
95%	1.2E-03	3.5E-01	4.8E-01	4.0E+00
100%	7.4E-02	3.5E+00	9.6E-01	1.0E+01

- Some regulatory agencies are focusing on 95%ile values
- USEPA database results may be biased by background impacts
- Be careful if simply using empirical factors

Baseline Vapor Intrusion Model
(Johnson and Ettinger, 1991)



Mixing in Breathing Zone

Convective Transport into Building

Diffusive Transport

Partitioning

- Simplified screening model (assumes 1-D transport)
- User inputs soil and building properties
- Background effects neglected
- Potential refinements may be considered

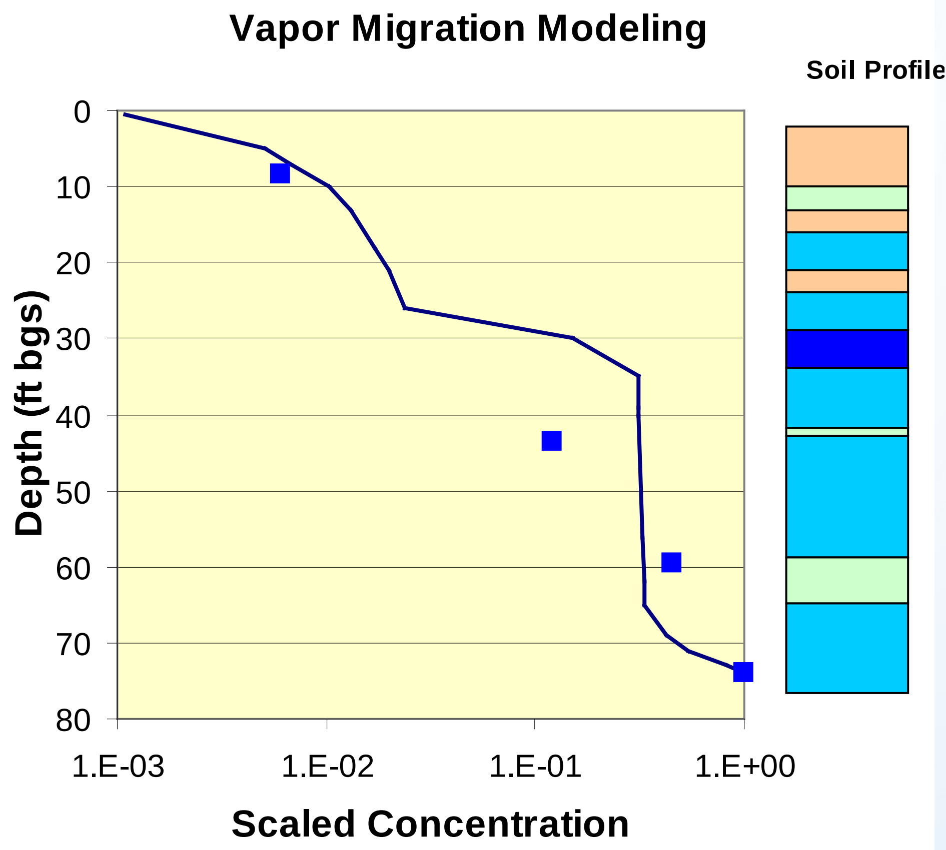
Geosyntec consultants

Baseline Vapor Intrusion Model

Soil Gas Profile Modeling

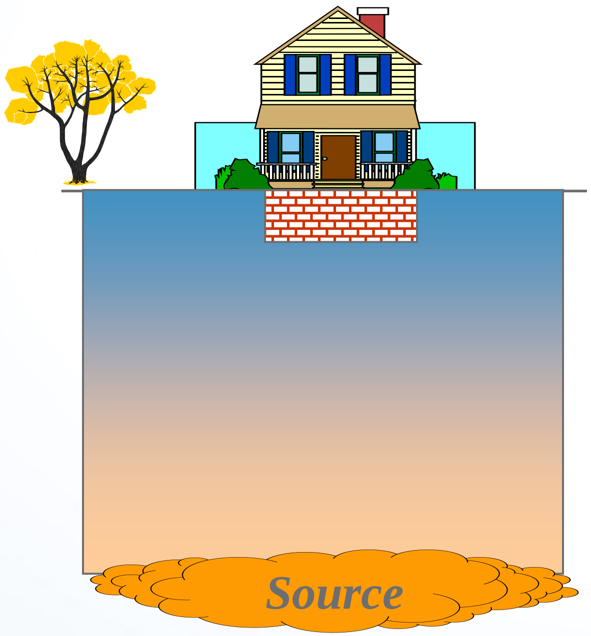
- Utilize
  - Soil lithology
  - Concentration measurements
  - Modeling
- Demonstrates understanding

  of sub-surface transport



Geosyntec consultants

BioVapor - Oxygen Limited Model (Devaull, 2007; BioVapor, 2010)



Mixing in Breathing Zone

Convective Transport Into Building

Biodegradation Zone

Diffusive Transport

Partitioning

http://www.api.org/ehs/groundwater/vapor/bio-vapor-intrusion.cfm

- Calculates diffusion of O_2 from surface as well as transport of organic vapors
- 1st order degradation in zone where O_2 above threshold value

Geosyntec consultants

Vapor Intrusion Critical Processes

Process	Key Considerations	Sensitivity
Diffusive Transport (Diffusive Flux)	Soil type, moisture content, presence of groundwater	VI decreases when higher moisture content soils are present
Bioattenuation	Hydrocarbon conc./ location, oxygen availability	VI can be insignificant with sufficient subsurface oxygen availability
Building Ventilation	Varies by building use/design	Increasing ventilation reduces indoor air concentrations
Soil Gas Convection	Default values typically used	Key parameter for sub-slab data or pos. press.
Partitioning	Groundwater to soil gas relationship	Uncertainty reduced by collection of soil gas samples

Geosyntec consultants

Data Collection Options

Process	Key Considerations	Measurements
Diffusive Transport (Diffusive Flux)	Soil type, moisture content, presence of groundwater	Continuous boring logs Soil property data In-situ diffusivity test VOC soil gas profile
Bioattenuation	Hydrocarbon and oxygen distribution	Hydrocarbon distribution Oxygen soil gas profile
Building Ventilation	Varies by building use/design	Building ventilation rate
Soil Gas Convection	Default values typically used	Cross-slab pressure
Partitioning	Groundwater to soil gas relationship	Soil gas samples for source characterization

Improving Vapor Intrusion Evaluation through Risk Management

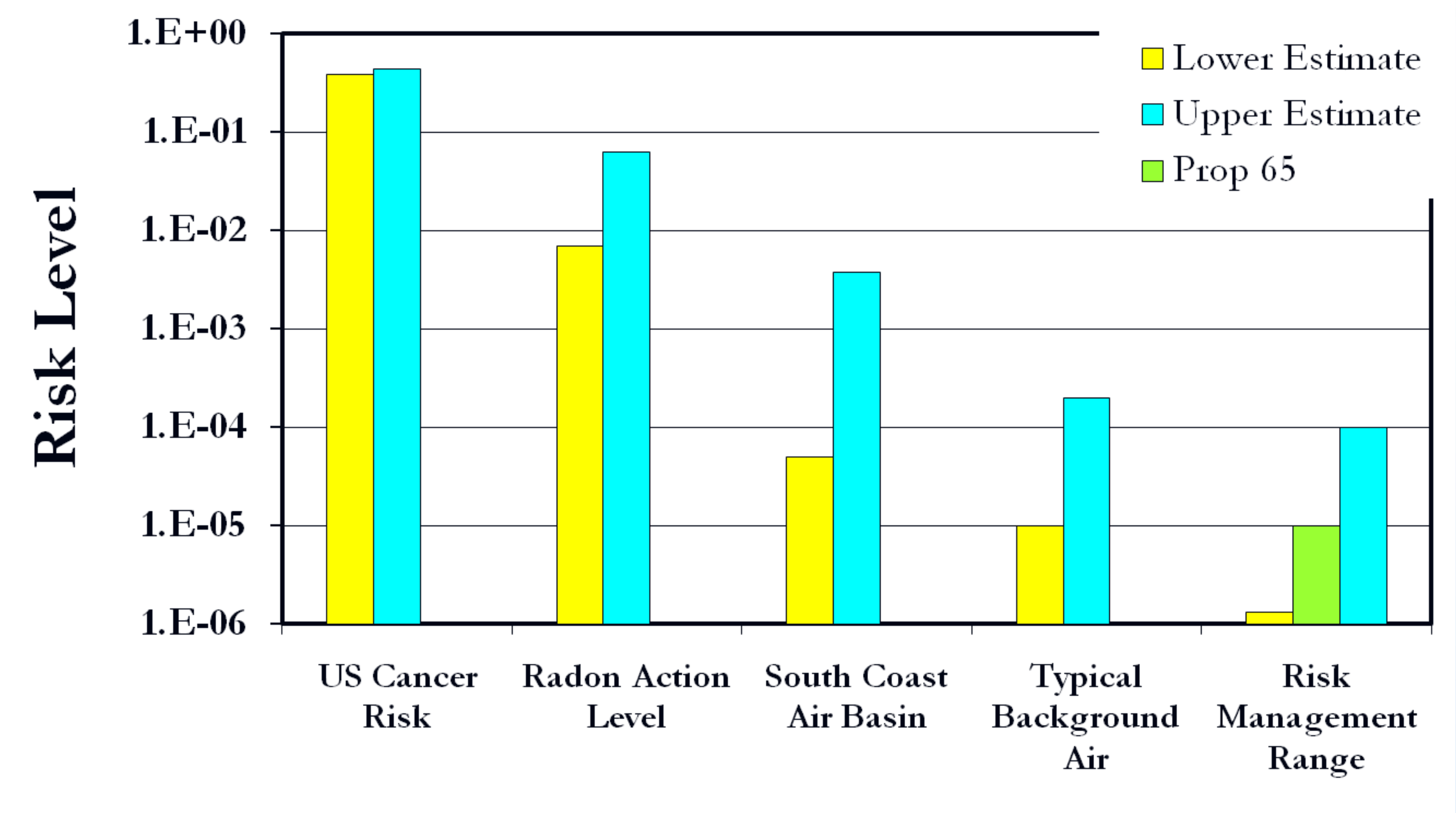
- Uncertainties in vapor intrusion pathway evaluation

Issue	Decisions/Factors
Target Indoor Air Concentration	Target Risk / Hazard Level Receptor/Exposure Assumptions Background Effects
Site characterization (investigation and modeling)	Source Characterization Data Uncertainty Model Uncertainty
Mitigation	Risk Reduction Costs (short- and long-term)

- These uncertainties can be addressed by considering risk management in decision-making process

Geosyntec consultants

Relative Risk Levels



Geosyntec.com
engineers | scientists | innovators

Target Indoor Air Levels

- Variability in target indoor air concentrations due to :
  - Toxicity assumptions
  - Exposure assumptions
  - Target risk level
- Also consider
  - Occupational standards
  - Background concentrations

Example Target Indoor Air Levels (Res./Comm.)

Basis	Benzene	PCE
10^{-6} Risk	0.084 / 0.14	0.41 / 0.69
10^{-5} Risk	0.84 / 1.4	4.1 / 6.9
10^{-4} Risk	8.4 / 14	41 / 69
Background	3 - 5	1 - 5
PEL (8-hr TWA)	3200	170,000

Concentrations in ($\mu g/m^3$)

Indoor Air Sampling

- Indoor air sampling may seem to be a direct assessment approach, but is typically conducted during higher tier of investigation
- Challenges to indoor air sampling
  - Occupant disruption
  - Temporal / spatial variability
  - Interpretation for future land development scenarios
  - Background effects

Geosyntec consultants

Example Background Indoor Air Concentrations

Table 2

Summary Statistics for Background Indoor Air Concentrations Measured in North American Residences Since 1990 (All concentrations in µg/m^3)

Compound	N Studies	N Samples	%Detect	RL Range	25%	N	50%	N	75%	N	90%	N	95%	N	Max	N
Benzene	14	2615	87	0.05 - 1.6	1.9	7	2.5	13	4.5	9	10	11	17	5	93	10
Carbon tetrachloride	5	873	88	0.15 - 0.25	0.3	2	0.5	5	0.7	2	0.8	4	1.1	1	2.7	3
Chloroform	10	2178	73	0.02 - 2.4	0.5	4	1.1	9	2.2	6	3.9	8	6.0	5	20.2	7
Dichloroethane, 1,1-	5	1309	0.3	0.08 - 2.0	<RL	5	<RL	5	<RL	5	<RL	5	<RL	4	0.9	5
Dichloroethane, 1,2-	4	950	12.6	0.02 - 0.25	<RL	2	<RL	4	<RL	3	0.15	4	0.20	2	1.8	4
Dichloroethene, 1,1-	5	957	10	0.01 - 2.0	<RL	4	<RL	5	<RL	5	<RL	5	<RL	3	86.8	5
Dichloroethene, cis 1,2-	4	975	3	0.25 - 2.0	<RL	4	<RL	4	<RL	4	<RL	4	<RL	3	3.7	4
Dichloroethene, trans 1,2-	3	575	0	0.8 - 2.0	<RL	3	<RL	3	<RL	3	<RL	3	<RL	2	<RL	3
Ethylbenzene	10	1484	81	0.01 - 2.2	0.8	4	2.0	9	3.0	5	8.6	7	14	3	126	8
Methyl tert-butyl ether (MTBE)	4	502	47	0.05 - 1.8	<RL	3	1.2	4	5.7	4	26	4	72	2	242	4
Methylene chloride	7	1,649	73	0.4 - 3.5	0.42	3	1.10	7	3.6	5	10	7	20	4	506	6
Tetrachloroethene	13	2312	64	0.03 - 3.4	<RL	7	0.9	10	1.8	6	4.0	9	7.4	5	171.2	8
Toluene	12	2065	96	0.03 - 1.9	9	5	13	12	27	7	51	9	106	4	547	9
Trichloro-1,2, 2-trifluoroethane, 1,1	1	400	56	0.25	<RL	1	0.5	1	1.1	1	1.8	1	3.4	1	7	1
Trichloroethane, 1,1,1-	9	1877	60	0.12 - 2.7	0.5	7	1.9	9	2.7	7	5.5	7	10.2	5	196	8
Trichloroethene	13	2403	44	0.02 - 2.7	<RL		0.3	10	0.3	6	0.9	8	1.6	5	84	10
Vinyl chloride	6	1684	7	0.01 - 1.3	<RL	6	<RL	6	<RL	6	0.03	2	0.05	2	0.8	6
Xylene, m/p-	10	1920	90	0.4 - 2.2	2.9	6	5.5	10	9.4	7	27	9	41	4	593	8
Xylene, o-	12	2004	85	0.11 - 2.2	1.4	6	2.2	11	3.9	7	10	9	16	4	196	10

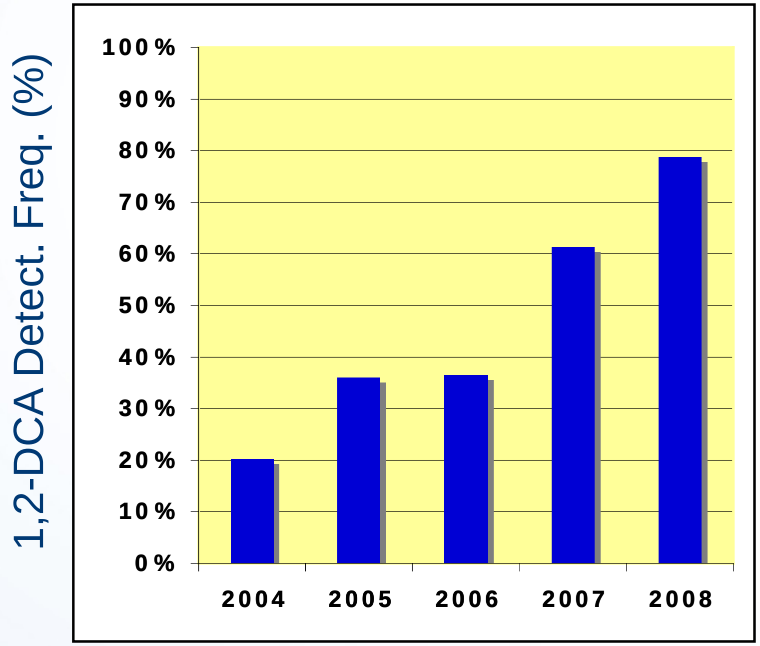
Note: "N" indicates number of studies reporting a particular statistic.

From Dawson and McAlary, 2009

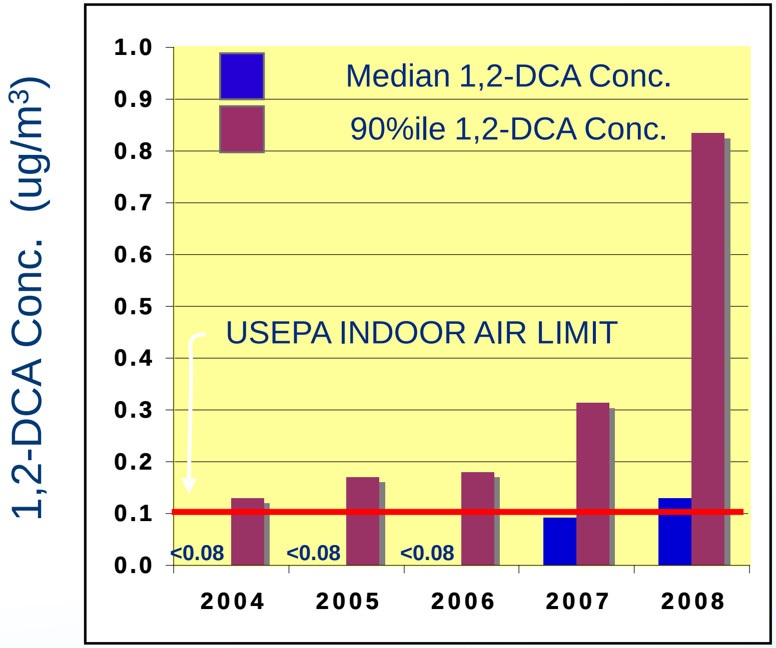
Consider background range as well as typical values

Background Concentration of 1,2-DCA

DETECTION FREQUENCY



CONCENTRATION



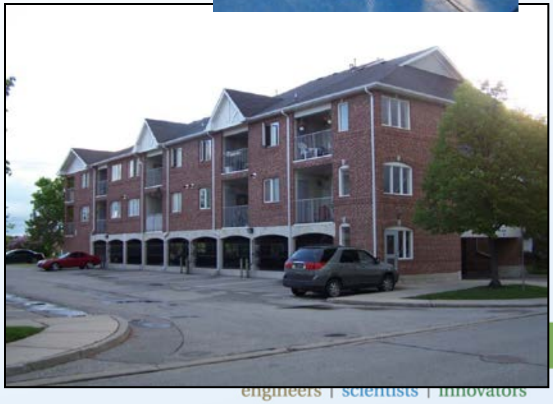
1,2 DCA Background Source:

Detailed study by Hill AFB identified molded plastic ornaments manufactured in China as source for 1,2 DCA.

Note: 1) 1,2-DCA = 1,2-dichloroethane
From McHugh et al., 2009. Also see Doucette et al., GWMR, 2010

Mitigation Options

- Active Remediation
- Institutional Controls
- Engineering Controls
  - Sub-Slab Depressurization "Radon System"
  - Passive Venting
  - HVAC Modifications
  - Indoor Air Treatment
  - Building Design (Brownfields)



Mitigation Technologies

Technology	Pros	Cons	Applications
Passive Barrier	Often simple addition to construction activities	Limited data on long-term effectiveness	New Construction
Passive Venting	Low O&M cost Upgradeable to SSD	Limited effectiveness	Lower concentration areas
Sub-Slab Depressurization	Proven technology Wide acceptance	Higher capital cost Air permitting needs variable	Similar to Rn systems. Proven effectiveness.
HVAC Operation Modification	Potentially low capital cost	High O&M cost Occupant comfort Difficult to control	Buildings with continuous HVAC operation
Indoor Air Treatment	Quick Installation	Potentially higher capital cost Difficult to control	Interim Measure

Consider O&M requirements when evaluating mitigation options

Institutional Controls and Pre-Emptive Mitigation

- Can be good risk management tool, but may result in redevelopment limitations
- Pre-emptive mitigation adds to redevelopment costs
  - Long-term effectiveness/ responsibility
- Business risks need to be considered along with health risks in decision process

Geosyntec consultants

Regulatory Risk Management Matrix

Consider risk management in decision-making process

Indoor Air Risk/Hazard[1]	Response(s)	Action(s)
Risk $\leq 1\times10^{-6}$ Hazard Index ≤ 1	None	• No Further Action
1×10^{-6} < Risk $\leq 1\times10^{-4}$ Hazard Index > 1	Risk Management Decision	• Monitoring; • Possible Mitigation[2] • Possible Source Remediation[2]
Risk > 1×10^{-4}	Mitigation Source Remediation	• Vapor Intrusion Mitigation System[3] • Source Remediation[3]

1 Estimated based on multiple lines of evidence, as established in the DTSC Vapor Intrusion Guidance.
2 Mitigation is intended to reduce the entry of VCs from a subsurface source into building air and should be conducted in conjunction with source remediation. DTSC does not consider a vapor intrusion mitigation system as a means of remediating the source of the subsurface contamination.
3 Both vapor intrusion mitigation and source remediation should be implemented for sites in this risk range. However, site-specific conditions (such as where the source of contamination is located off-site) may necessitate use of mitigation as the long-term measure.

From DTSC, 2009. Vapor Intrusion Mitigation Advisory

Geosyntec consultants

Summary

- Variety of models available, but limitations must be understood to assess if the selected model is appropriate for site conditions
- Uncertainty in model estimates has been assessed and conservative assumptions are used for default evaluations
- Site-specific model input values require appropriate justification
- Understanding the uncertainties in the site-specific investigation will enhance evaluation process through improved site investigation, modeling, and mitigation
- Risk management tools should be used to balance uncertainties in evaluation process